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Solar Brine Concentrator

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Solar Brine Concentrator

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by

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This thesis is approved.

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University of Arkansas

Task 4: Solar Brine Concentrator

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EXECUTIVE SUMMARY

In arid regions of the United States potable water is a valuable resource and is sometimes produced using energy intensive processes by removing salts from brackish water. Task 4 provides a solar option for producing potable water from brackish water; in competing in Task 4, H_2OGS has developed a simple, cost effective solar desalination process to provide these regions with necessary, potable water. H_2OGS' design takes into account WERC requirements, including cost, energy usage, worker safety, and easily obtained materials. U.S. government regulatory requirements are also taken into account as the proposed location for this process is Alamogordo, New Mexico.

H_2OGS' design consists of a thin plate-type solar evaporator and also a thin plate-type condenser. Black-painted corrugated galvanized steel panels were used to construct the evaporator and condenser. The black-painted evaporator panels are protected from atmospheric convection by a six mil polyethylene film, commonly used for greenhouses. Radiant energy from the sun passes through the polyethylene film and is absorbed by the black-painted panel. Brine is sprayed onto the back side of the panel via a nozzle located at the top of the unit. As the brine runs down the evaporating face, it is evaporated. The warmed, evaporated brine gravity drains to an insulated holding tank from which it moves to the next evaporating stage to be further concentrated. The evaporated water is condensed on additional corrugated steel plates located opposite the evaporating face. Because this plate is shielded from direct sunlight, the evaporated water is condensed by convection to the atmosphere and drained into a holding trough at the bottom of the unit where it is pumped to a potable water storage tank. The brine effluent that remains after leaving the final still unit is transported to a solar pond where salts crystalize and are removed by manual raking from the evaporation basin. This basin is designed to be 3' deep by 45' wide by 180' long and will evaporate the remaining 20% of the bring effluent and allow for crystallization and recovery of the salts. After air drying, the salts are sold.

The health and safety of all individuals involved in the H_2OGS project is important during the construction and the life of the project. The individuals involved in construction will be trained on the proper safety precautions before construction begins. Warning labels concerning the temperature of the unit will be printed on the solar brine concentrator. Regular

and preventative maintenance will be performed by a trained individual(s) to keep the unit running safely and efficiently.

The public involvement plan is crucial to the success of the solar brine concentrator in Alamogordo, New Mexico; this technology would be competing with the city's current technology. Meetings will be held to inform the community of the benefits and disadvantages of both technologies. These meetings will help educate the community and address any community concerns. A training session will be held concerning operation, maintenance, and safety precautions of the facility.

The H_2OGS full scale unit will produce 25 L/day/person (1/2 of the UN minimum per day) for a community of 500 people or 12,500 L/day (3,300 gpd, 1.2 million gpy). The installed cost of the unit is $100,000. With capital cost amortized over 10 years the yearly capital charge is $10,000. With community volunteer labor the operating costs are $10,000/yr. With 15,600 L/day of brine feed the produced salts will be 198 lb/day (66,000 lb/yr). At a salt netback price of $0.33/lb, the benefits of salt sales are $21,780/yr. The salt sales will thus cover both capital charges and operating costs, assuming volunteer labor. This optimistic scenario will produce water at zero cost to the community. The current Alamogordo water cost for large volume users is $7.91/k gal[23]. With operating labor included at $50,000/yr the cost of water will increase to $40.01/k gal.

The following report provides a detailed proposal of the solar brine concentrator, including design concepts, experimental results, health safety and environmental concerns, and a public involvement plan. While the design is recommended for Alamogordo, NM, H_2OGS has designed the unit to be implemented anywhere there is a real need for potable water near a usable brine source.

1.0 SITE BACKGROUND

For the WERC Task 4 problem, a low cost, low energy, and safe solar brine concentrator made from easily obtained materials is required. H_2OGS researched areas with needs for potable water due to low rainfall, scarce resources, and expensive water technology. Alamogordo, NM is the location of our brine source; the city currently uses expensive reverse osmosis to purify their water. Alamogordo is an ideal site for H_2OGS' solar concentrator because it has a brine source which is identical to the Task 4 feed and it has a need for economical potable water.

Alamogordo has a population of about 32,000 people. The average temperature, precipitation, and insolation (average solar flux) are displayed in Table 1. The US Bureau of Reclamation Brackish Groundwater National Research Facility in Alamogordo, NM operates 4 brine wells for research purposes and one of the wells is the source for the Task 4 brine. Table 2 presents the given Task 4 brine composition compared to the brine composition from well 2 of the research facility.

Table 1. Environmental Conditions of Alamogordo, NM[8]

Month	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.
Average Temperature (◦C)	13	16	20	25	30	34	34	33	30	24	18	13
Average Precipitation (mm)	18.3	16.5	10.7	9.7	12.4	20.1	46.0	55.6	37.6	29.7	18.3	23.6
Insolation (kWh/m /day)	2.93	3.66	4.92	6.13	6.65	6.62	6.04	5.46	5.01	4.09	3.26	2.70

Table 2. Given Brine and Suspected Source Concentration Comparison[16]

	Task 4 Concentration (ppm)	**Alamogordo, NM Well Concentration (ppm)**
bicarbonate	299	250
sulfate	3227	3200
chloride	569	620
nitrate	34	8.3
sodium	707	695
potassium	2.9	2.9
magnesium	378	340
calcium	597	550
strontium	9.6	8.8
barium	0.01	0.01
silica	22	23

2.0 LAB TESTING UNIT

In order to demonstrate the production of potable from the Task 4 brine a laboratory unit was constructed. The unit was constructed using the same engineering principles as the full-scale unit. A schematic of the unit is presented in Figure 1. Plexiglas was used on the sides of the unit to allow for viewing of the process, two stainless steel plates were used as the evaporating and condensing surfaces, and wood was used for the remainder of the construction for convenience and cost. Testing of spray nozzles determined that an inexpensive, lawn irrigation spray nozzle was best for this application. The spray nozzle selected maintained constant, uniform flow over the SS evaporating surface.

The SS plates were 9.5” x 9.5”. One of the SS sheets was used for the evaporating surface and the other was used for the condensing surface. The condensing SS plate was bent 1.5” from the lower end at a 60 degree angle to form one half of the product collection trough. The trough construction is shown in Figure 1. The evaporating sheet was painted black on the radiation absorption side. Half inch thick plywood was cut into two 10” x 4” lengths, two 8.5” x 4” lengths, and one 8.5” x 11” length, which were used to construct a 4” deep brine basin which was then sealed with silicone. The metal plates formed the ends of the unit and ¼” Plexiglas plates for the sides of the unit. A 5” x 5” access window was fabricated into one Plexiglas side to provide access inside the unit. Once all the edges were sealed a ¾” x 7” x 12” piece of plywood was bolted and sealed on top of the unit creating a fully enclosed evaporating and condensing chamber.

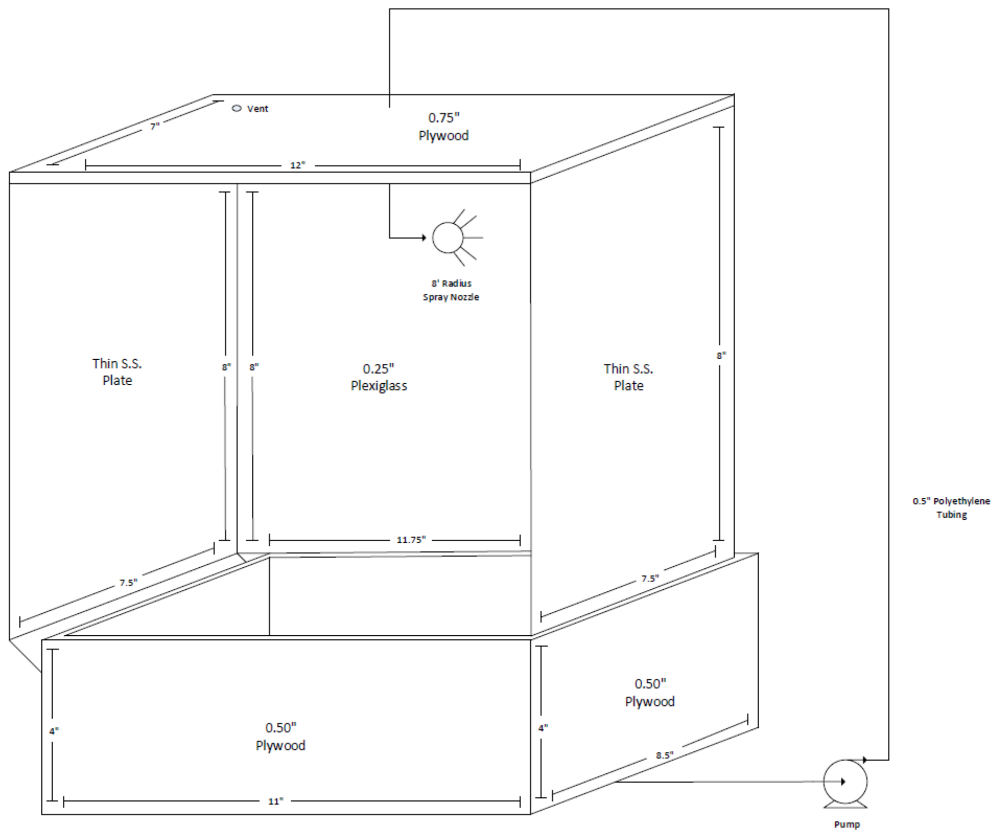

Figure 1: Visio drawing of lab experiment unit.

To prevent convection from transferring heat from the blackened hot plate to the room air a piece of plastic wrap was stretched over a wooden frame to create a barrier between the plate and the ambient air. This film provides a convective thermal barrier between the black-painted SS surface and the room atmosphere. The condensing plate is exposed to the atmosphere to allow fan cooling of the condensing plate.

A ½" Tygon hose was attached through a ½" hole in the side of the basin and connected to a 1/40 hp pump below the apparatus which was used to pump the brine solution from the basin to the spray nozzle located at the top of the unit. Near the nozzle opening at the top of the unit is a vent to prevent the unit from over pressurizing while the brine is being heated and evaporated by the blackened plate. To prevent unnecessary heat loss throughout the unit, 2" fiberglass insulation was wrapped around the top, bottom, and Plexiglas sides, and the unit was placed upon 1" thick Styrofoam insulation.

2.1 Experimental

In order to test the lab unit as a proof of concept design, the apparatus must run on a continuous cycle, evaporate the brine solution, and produce potable water on the condensing stainless steel surface. Water was pumped from the bottom reservoir, through a spray nozzle located at the top of the unit, and ran down the evaporating surface on the inside of the unit. Heat was then applied to the stainless steel evaporating surface by a 1 kW shop light. The radiation from the light was absorbed onto the blackened surface and, subsequently was transferred by conduction through the SS plate to the opposite side where the sprayed brine was evaporated. The evaporated water moved to the opposing side of the unit where condensing occurs on the fan cooled SS surface. The condensate ran down the condensing surface into the trough at the bottom of the plate and then into a tube which conveyed it outside the unit for collection in a beaker.

The closed system was run continuously for four hours inside the lab. The plate reached and maintained a temperature of 50°C. The fan maintained the stainless steel condensing surface at 21°C. The water temperature reached a temperature of 45°C. Condensation began to appear on the condensing surface after 10 minutes of operation. Over the course of the four-hour experiment, the unit was able to produce 37 mL of water. With a startup time included in the process, the unit is able to produce around 10 mL per hour.

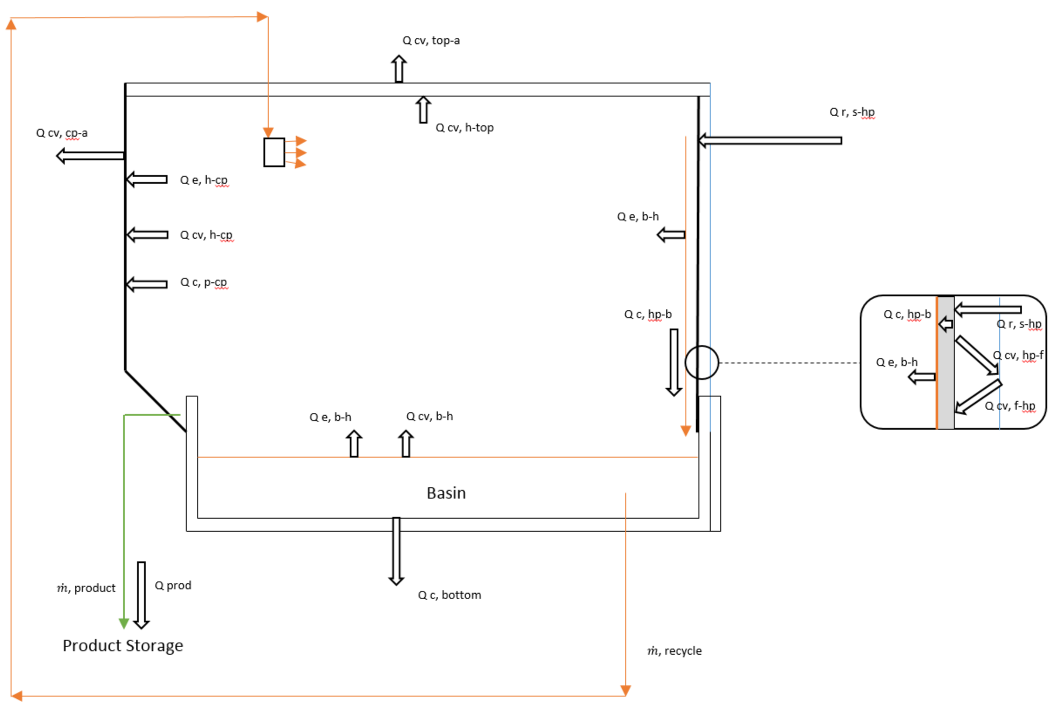

Figure 2: Heat and Mass balance of lab experimental unit

3.0 PROTOTYPE UNIT DESCRIPTION

In order to demonstrate the operation of the full-scale design, a prototype unit, meeting the design specifications of the full size unit, was designed, built, and operated. The full scale unit will have 16’ long panels; the prototype unit has two 8’ long x 26” wide corrugated, galvanized steel panels as shown in Figures 3, 4, and 5.

Figure 3. Photograph of the prototype unit during assembly.

Figure 4. Photograph of the assembled unit as used for testing.

Taking the average heat from the sun over the course of a twelve-hour day to be 200 W/m^2, the convective surface of 1.5 m^2, and the latent heat of water to be 2,300,000 J/kg, the unit will produce 4 L/day at a 100% efficiency, and 3 L/day at the expected efficiency of 75%. Preliminary testing is complete and the non-optimized unit produced 75 mL/hr of condensed water during the time period 2:00 – 5:00 P.M. For a 12 hour day at this rate the daily production would be 0.9 L/day which is an efficiency of 23%. The unit was not sealed well and there was significant water evaporation as the heated brine flowed from the evaporation panel into the feed pump surge tubs. These inefficiencies will be eliminated when the unit is tested in Las Cruces at which time the expected efficiency will be about 50%.

Figure 5. Photograph of the spray nozzle in operation.

The unit operates as a continuous, steady state process. A piston pump moves brine water from a plastic water containers to a spray nozzle as shown in Figure 4. The spray nozzle distributes water over the heated corrugated steel panel. The water runs down the steel surface into a trough which drains into the brine reservoir as shown in Figure 4.

Radiation is absorbed by the black-painted surface and is transferred to the back side of the steel panel where the brine solution is evaporated. The evaporated water moves from the heated side of the still to the condensing side where it is condensed by convection to ambient air. The condensed water travels down the steel surface into a trough below and then travels into produced water collection tubs, one on either side of the unit.

To prevent spray on the heated side from moving to the condensing side a spray guard as shown in Figure 5 was installed. The spray guard stretches across the width of the unit. A space is left at the bottom and the top of the spray guard to allow the evaporated water to move from the heated side to the condensing side. This allows the water that falls or condenses on the floor of the unit to flow to the proper trough.

4.0 FULL SCALE PROCESS SUMMARY

4.1 Technologies Considered

Table 3. Solar Pond and Solar Still Comparison[10,13]

Technology	Advantages of Technology	Disadvantages of Technology
Solar Pond	• Low cost • Removed salt can be a valuable by-product	• Inefficient • Requires a lot of maintenance • Requires a large land area • Needs adequate sunlight
Solar Still	• Simple operation and maintenance • Materials of construction readily available • Removed salt can be a valuable by-product • Produces high-purity distilled water	• Multiple units are required for large production rates • Needs adequate sunlight

4.2 Process Overview

A sketch of the cross-section of the full scale design is presented in Figure 10. The full scale teepee brine concentrator system designed calls for the brine solution to be transported 14 feet vertically from a 4’x4’x8’ brine collection tank to the top of the teepee where it is distributed evenly across 2000 lineal feet of 26 gauge corrugated steel tin roofing. The brine solution is vaporized by means of the heat transferred through the corrugated steel from the sun’s radiation. The recirculating brine solution is drained into a trough underneath the blackened corrugated roofing into the within ground storage tank from which it is pumped back to the spray heads. The heated, black painted panels face the sun and the condensing, unpainted panels face away from the sun.

The vapor is condensed on the other side of the teepee, which is kept separated from the heated side by means of a polyethylene film barrier. The vapor condensed on the condensing surface runs down the cool corrugated steel where it is collected in a trough through which is flows to a potable water storage tank. During hot weather, fans will be used to aid cooling of the condensing panels.

The brine solution is distributed among the surface of the heated corrugated steel by the use of the piping and sprayer system described below.

4.3 Process design

The full scale design is composed of five identical 400 foot long units in parallel, each with two pumps. Each unit has a marine plywood, insulated 4’x4’x8’ tank in between its two half-units where the brine solution is stored. The brine solution is pumped by two 50 gpm centrifugal pumps from the brine storage tank into two headers along which are situated 100 spray nozzles. A half-unit covers a 200 foot long teepee and delivers 100 gpm of brine solution by the use of 50 orbit shrub sprayers each spaced 4 feet apart with the first sprayer 2 feet away from the edge, and each delivering two gpm. A half-unit is composed of four sections: each 50’ length with decreasing header pipe diameters of 1.5”, 1.25” 1”, and 0.75”. The pipe diameter is decreased in order to maintain the fluid velocity fairly constant throughout the system providing adequate pressure for the sprayers to supply brine water at a constant rate. The decrease in sizing is made possible by the use of couplings and bushings, the sprayer is connected to the tee by a nipple like the one showed below in Figure 6 which also shows a bushing and tee used for the sprayer system. The decrease in pipe diameter is shown below in Figure 7 where a 1.25” pipe is reduced to a 1” diameter pipe.

Figure 6. Photograph of a Bushing, nipple, and tee respectively.

Figure 7. Decreasing pipe diameter from 1.25" to 1" with sprayer.

The pressure drop across the sprayer was measured to be 8 psig by means of a pressure gauge during prototype testing. A 1.5 horsepower pump is adequate to supply the required 50 gpm. Figure 8 is a schematic of the brine sump, brine pumps, transfer pump, header system, and spray nozzles.

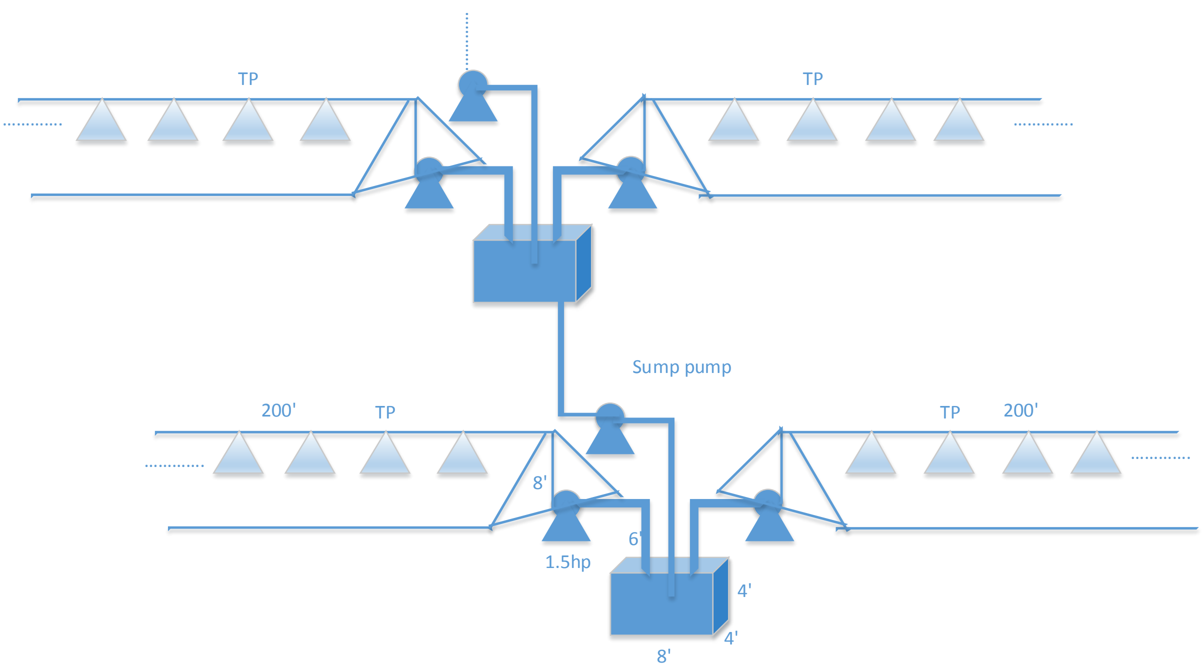

Figure 8. Two units of the full scale design.

4.4 Teepee Construction

A polyethylene covering used for greenhouses is tightly pulled over the wooden frame built for the heated side of the 26 gauge corrugated steel, which is spray painted black to increase absorptivity from the suns radiation. The wooden edges of the heated side frame were relieved at 45 degree angles to minimize the heat absorbed into the wood frame directly underneath the polyethylene film. The condensing side also had a wooden frame, but no plastic covering. The cooling side in hot weather will be cooled by fans. The heated and condensing sides will be separated, to prevent spray migration from the heated side to the condensing side by a barrier as shown in Figure 4. Polyethylene sheet is placed underneath the unit at angles to the horizontal, as shown in Figure 9, to allow the spray brine to flow into side troughs and to allow the condensed water to also flow into a different side trough.

Figure 9. Photograph of polyethylene sheet.

A two-dimensional view of the front side of the teepee without the plastic covered parts is shown in Figure 10.

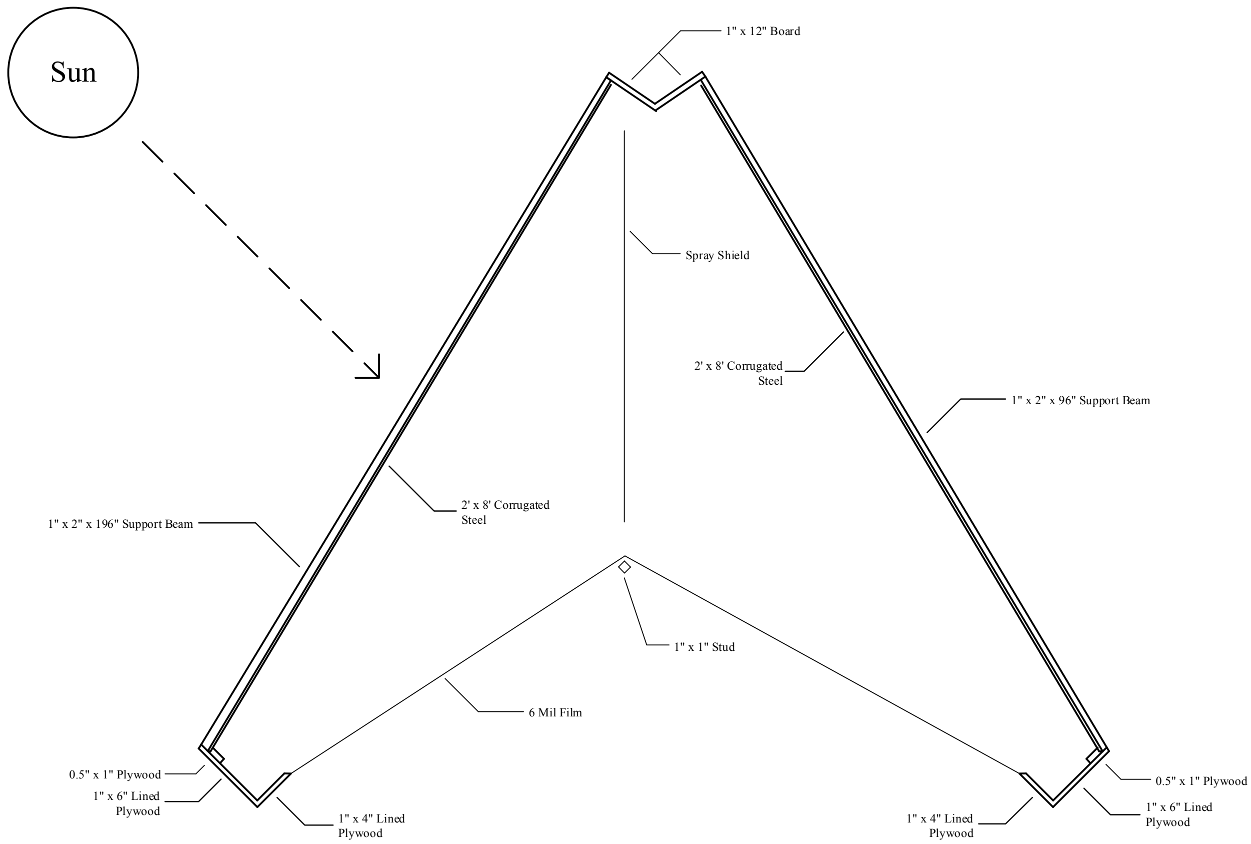

Figure 10. Cross-sectional view of the teepee.

4.5 Evaporation Pond

A positive displacement pump will be used to transfer the crystalized salts to a polyethylene tank. This tank will be transported via trailer to an evaporation pond. The evaporation pond will be used at the New Mexico site to produce crystallized salts from the concentrated brine. The size of the salt evaporation pond was determine based on the 80% of the feed brine being evaporated. Annual evaporation from surfaces of water bodies in New Mexico is about 63.6 in/yr which is 1.325 in/week[6,7,12]. With a premise of 80% evaporation of the brine the evaporation required by the evaporating pond is [(1.2 million gal/yr)/0.8]0.2=300,000 gal/yr (40,000 ft^3/yr). At an evaporation rate of 5.3 ft/yr the required surface area is 7,500 ft^2. This requires a square evaporation pond of approximately 90 ft/side, or about ¼ acre. This pond will probably be built about 3' deep with dimensions of 45'x180' so the crystalized salts can be raked out of the pond from either side and be spread out to dry. The pond will be lined with two layers of 6 mil polyethylene film.

5.0 USES OF BRINE CONCENTRATE

Dairy cattle have specific feeding requirements, and require supplements to be added to their feed. The salts and concentrated brine produced from the brine concentrator can be used as supplements for dairy cattle, as it contains most of the macrominerals required. It is important that dairy cattle not only obtain all the nutrients required, but the correct amounts of each nutrient. Under or overfeeding a nutrient can cause health problems, and overfeeding specifically can cause certain nutrients to become toxic to the cattle[2].

Phosphorus is an important macromineral required by dairy cattle and has more functions than any other mineral[2]. Unfortunately, the brine used for this project does not contain any phosphorus. If used for dairy cattle supplements as H_2OGS has proposed, the brine will need to be supplemented with the appropriate phosphorus. Additional NaCl will also need to be added to the feed along with the brine to meet dairy cattle nutrition requirements

These salts would need to be transported to the dairy farms from our site location. Figure 11 shows dairy farm locations in a portion of New Mexico. There are many dairy farms in New Mexico which would provide a market for these supplements.

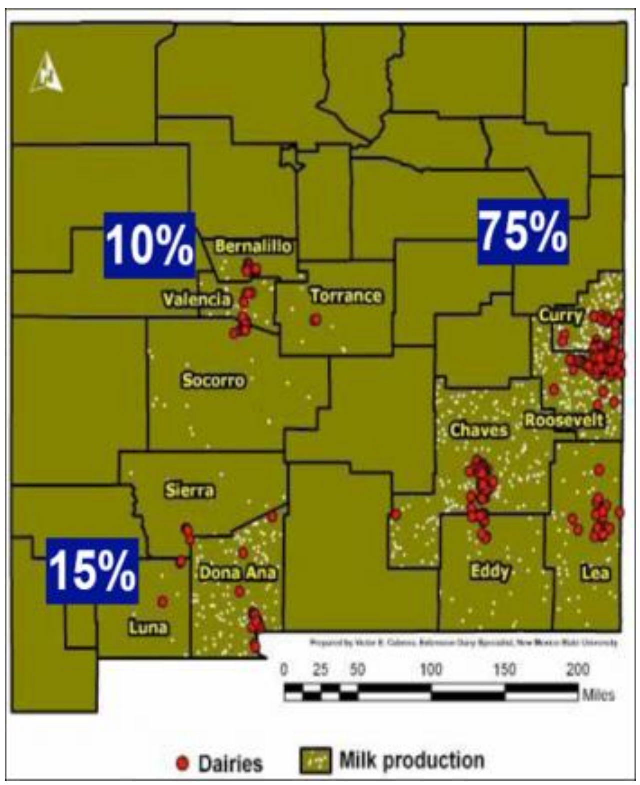

Figure 11. Map showing locations of dairy farms[9].

With our site being located in Alamogordo, NM transporting the salts in solution would be difficult. The maximum transportation distance for a wet supplement is approximately 50 miles, and the recommended distance is only 30 miles[15]. The salt produced will need to be dry for further transport. Additionally, wet additive will make dry feed soggy, which could potentially cause cattle not to eat the feed.

Halophytes are a type of plant that thrives in high salt saline concentrations and arid climates. Halophytes can be found on the shores of highly salinated waters, like oceans and seas, and sometimes in land where there is salinated water and arid conditions. It was once thought that halophytes did not have many uses but they are actually quite useful when it comes to agriculture.

Plants of the *Atriplex* genus are typically referred to as salt bush because they usually contain salt in their leaves. *Atriplex* is a genus of halophytes that can be found all over the world including in North America. Any genus of *Atriplex* can be used to feed livestock especially those requiring salt in their diet. When feeding livestock, *Atriplex* can be used in a similar format as hay in that it can be administered as a dry feed alone or in water. Using *Atriplex* as a livestock feed reduces the amount of money spent purchasing salt lick blocks. With less demand, there would be less supply and a reduction in the energy used to create such blocks.

In areas where salinated water is available in wells and springs as ground water or as a result of potable water, the salinated concentrate, when diluted with available brackish water can be used to irrigate fields where *Atriplex* is grown.

Atriplex is not only a good source of nutrients for livestock, but *Atriplex* also has a history of being used as fertilizer. Native Americans of the southwest would burn *Atriplex* bushes and use the ashes as fertilizer. Studies have shown that plants grown with *Atriplex* ashes as fertilizer have more nutritional value than those not grown with *Atriplex* ashes as fertilizer. Studies have not yet indicated whether or not *Atriplex* must be burned to have the same effect or if it can be spread along the ground as hay or cornstalk is for mineral content. It is certain, however, that livestock can be fed *Atriplex* as they are fed hay cornstalk. The salts exiting the full scale process can be used to grow *Atriplex* which can be used directly as supplements to animal feed[3, 11, 21, 22].

Phosphorous is a nutrient essential to most life forms because of the phospholipid bilayers of cells which life forms are composed of. Phosphorus is mentioned because the concentrate produced from this solar still contains a majority of the nutrients needed to sustain both beef and dairy cattle but severely lacks phosphorous. This concentrate can be used as a cattle supplement if phosphorus is added. A suggestion for obtaining phosphorus is to feed cattle cornstalk using the concentrate as a foliar for the cornstalk. The salts contained in the feed brine are deficient in phosphorus if they fed to cattle. However, corn is high in phosphorus and its stalk is high in phosphorus. A mixture of *Atriplex* and corn stalks is an ideal feed supplement for cattle, especially dairy cattle. Using the salts from this project to grow *Atriplex* is another means of using the produced salts beneficially, however using them directly for cattle feed supplements is thought to be a better option.

6.0 ECONOMIC ASSESSMENT AND BUSINESS PLAN

The duration of the construction of the full-scale unit will be about two months. A public involvement plan will be proposed which will compare this technology to the technology currently being used. The capital cost of this full scale unit was determined for the following three scenarios.

- Highest capital and operating cost
- Expected capital and operating cost
- Lowest feasible capital and volunteer operating labor

Table 4. Itemization of cost for full scale unit

ITEM	QUANTITY	UNIT COST	TOTAL COST
PUMP AND SPRAYERS			
1.5HP, 3450 RPM, 115V Pool Pump	10	$ 413.75	$ 4,137.50
0.33 HP Sump Pump	4	$ 112.85	$ 451.40
Orbit Plastic Shrub Head Sprinkler	500	$ 1.79	$ 895.00
Sub-total			$ 5,483.90
PIPING AND FITTINGS			
1.5" x 10' - 330 psi PVC DWV Pipe	25	$ 5.03	$ 125.75
1.25" x 10' - 370 psi PVC DWV Pipe	25	$ 4.49	$ 112.25
1.0" x 10' - 450 psi PVC Pipe	25	$ 3.33	$ 83.25
0.75" x 10' - 480 psi PVC Pipe	25	$ 2.25	$ 56.25
1" x 0.5" Tee	130	$ 1.00	$ 130.00
1.5" x 0.5" Tee	130	$ 1.18	$ 153.40
1.25" x 0.5" Tee	120	$ 2.01	$ 241.20
0.75' x 0.5" Tee (10 pack)	12	$ 3.26	$ 39.12
1.5" - 1.25" Bushing	10	$ 1.26	$ 12.60
1.25" - 1" Bushing	10	$ 1.26	$ 12.60
1" - 0.75" Bushing	10	$ 1.13	$ 11.30
1.5" Coupling	10	$ 0.76	$ 7.60
1.25" Coupling	10	$ 0.66	$ 6.60
1" Coupling	10	$ 0.46	$ 4.60
0.75" Coupling	10	$ 0.27	$ 2.70
ADJ Pattern Female	500	$ 0.76	$ 380.00
Sub-total			$ 1,379.22
TP SURFACE AND WOOD FRAME			
26 Gauge Corrugated Steel	2000	$ 14.96	$ 29,920.00
16' x 150' Green House Plastic	28	$ 358.95	$ 10,050.60
2" x 4" x 16' Plank	157	$ 7.66	$ 1,202.62
2" x 6" x 16' Plank	750	$ 10.94	$ 8,205.00
2" x 2" x 8' Plank	750	$ 1.82	$ 1,365.00
1" x 12" x 8' Plank	500	$ 11.98	$ 5,990.00
1" x 6" x 12' Plank	334	$ 9.54	$ 3,186.36
4' x 8' Marine Plywood Sheet	25	$ 30.00	$ 750.00
1" x 4" x 12' Plank	334	$ 5.83	$ 1,947.22
Sub-total			$ 62,616.80
COST OF CONSTRUCTION LABOR			
Workers	4		
Pay Rate		$ 25.00	
Hours	320		
Sub-total			$ 32,000.00
MISCELLANEOUS ITEMS			
Silcone		$ 10.42	$ 500.00
Black Spray Paint		$ 7.52	$ 500.00
DW Screws		$ 5.08	$ 500.00
310 Gallon (44" x 55") HDPE Vertical Tank	1	$ 535.00	$ 535.00
0.4' Polystyrene Insulation	20	$ 9.98	$ 199.60
Sub-total			$ 2,234.60
TOTAL COSTS			
Overall Cost			$ 103,714.52
10% Contingency			$ 10,371.45
Total Cost			$ 114,085.97
Overall Cost with 20% Discount			$ 89,371.62
10% Contingency			$ 8,937.16
Total Cost			$ 98,308.78

6.1 Scenario One

The itemization of costs for the full scale unit is located in Table 4. These prices are based on buying in small quantities. For this scenario, it is expected that no discounts will be obtained on materials bought in large quantities. With 10% contingency and four construction workers for two months the total cost for materials and labor will be approximately $110,000. It is reasonable to write off the capital cost over 10 years giving a capital charge of $11,000/yr. At least one operator will be required to operate and perform maintenance on the unit for 2000 hr/year at $30/hr requiring $60,000/yr. The total yearly cost for operation and maintenance materials with an allowance of $10,000 for miscellaneous needs is $81,000/yr.

For a town of 500 people, 25 L/person/day of water will be produced. Extrapolating this over an entire year gives a total water production of 4,562,500 L/yr (1,204,500 gal/yr). Potable water cost in the United States is typically stated as $/1,000 gal and varies from $2.50 to $5.00 per 1,000 gal. With the premises of scenario one, the water produced by this project will cost $67.25/1,000 gal.

The salts produced from the unit would not be sold. There would be an additional cost to remove and dispose of these salts. Additional environmental regulations regarding waste would need to be investigated for this scenario.

6.2 Scenario Two

Assuming materials bought in large quantities receive a 20% discount, the adjusted cost for materials and labor, including 10% contingency, is $98,000. With the same 10 year payoff plan, and a reduced operator salary of $25/hr the annual capital charge is $70,000.

The potable water produced in this scenario is the same of that produced in Scenario One. Because of the reduced capital charge the price of water produced is lowered to $58.12/1,000 gal. This price can further be reduced by selling the salts as an animal feed supplement. The produced salts will be about 66,000 lbs and assuming a selling price of $0.20/lb, the new water cost is $47.33/1,000 gal. This scenario is expected for the full scale unit.

6.3 Scenario Three

With all operating and maintenance labor done on a volunteer basis and material costs remaining the same as in Scenario Two the total capital cost with 10% contingency is $19,800/yr over 10 years. If the salts produces are sold at $0.33/lb the potable water produced by the brine concentrator would come at no cost to the community.

7.0 HEALTH SAFETY AND ENVIRONMENTAL CONSIDERATIONS

In addressing health, safety, and environmental regulations, H_2OGS investigated regulations on both the state and federal level. For the environmental regulations, possible water runoff and drinking water standards were considered.

The New Mexico Environmental Department requires National Pollutant Discharge Elimination System (NPDES) permits established by the Clean Water Act Section 402. The Environmental Protection Agency (EPA) outlines the categories which are required to obtain NPDES permits. To remain in accordance with the New Mexico Environmental Department and the EPA a Storm Water Pollution Prevention Plan (SWPPP) will need to be created and the appropriate NPDES permits will need to be acquired[4, 14, 17].

The Safe Drinking water act regulates the quality of Americans' drinking water[19, 20]. According to the EPAs National Primary Drinking Water Regulations the barium level in drinking water must be under two ppm. Nitrates must be under ten ppm. The potential health effects from long term exposure for amounts higher than the regulated amount for barium is increased blood pressure and nitrates can cause infants under six months of age to become seriously ill[18]. The potable water produced from the apparatus will need to be monitored to ensure they are within these ranges.

H_2OGS strives to have a safe unit and procedure for the city of Alamogordo. Safety precautions need to be taken for thermal, weather, and unit operations. The unit will operate at around 45-70°C so protective gloves should be worn and the drinking water that is outputted should be given adequate time to cool. If unplanned contamination occurs during the concentration procedure continue operating under a warning until the contaminated water leaves the still and then thoroughly clean out the apparatus. During the summer season, the concentrators should operate at times to avoid the heat, during the morning or evening. Workers should be fully hydrated throughout the entire day. All contractors and operators will be trained on the site safety rules before work begins. All personnel will be trained on emergency planning and response including evacuation procedures, first aid, who to contact.

8.0 PUBLIC INVOLVEMENT PLAN

The city of Alamogordo, New Mexico currently has a population of about 30,000 people and is currently in need of alternative water supply sources to meet the demand of the growing population[1]. A public involvement plan will be implicated to educate the city of Alamogordo on why the solar brine concentrator is the most beneficial water technology for their community. The second objective is to familiarize the community with the design and process of the concentrator.

Currently the city of Alamogordo is using reverse osmosis to produce pure water and a concentrate. Randy Shaw, facility manager and engineer at the US Bureau of Reclamation Brackish Groundwater National Research Facility in Alamogordo, revealed that reverse osmosis is expensive due to the type of membrane used and the use of high pressure and energy[1].

A presentation of the benefits will be given to the water department and others who want to be involved in the water project at the Alamogordo commission meetings which are held every other Tuesday of the month. The public involvement plan is constructed to educate the community, and address their concerns.

With the community, H_2OGS will schedule education meetings that will address the operation, maintenance, safety precautions, and site location of the concentrator. Training will be conducted and will be tailored to those with technical experience. To ensure safety and proper operating procedures an annual site check will be performed by a trained community member. H_2OGS's contact information will be available to community members in case any concerns arise. The cost of the public involvement plan is minimal relative to other costs. H_2OGS aims to gain the trust of Alamogordo's public and ensure them that the solar brine concentrator will be valuable. Any meetings with the community will continue until all of the public's questions are addressed.

9.0 SCALABILITY

The need for a large scale unit capable of supplying a small town with 3,300 gal/day of potable water was considered early on in the design stages of the project. H_2OGS decided that building a smaller unit and then scaling up was not ideal in terms of design as this would require a more complicated support system adding to the overall construction cost of the unit. Creating a full scale design and using a small segment as the prototype unit for testing purposes was a much more effective way to address the issues of structural integrity and cost.

The prototype unit is designed to be directly scalable to the full sized unit as the only significant difference between the prototype and the full scale design is the corrugated panels' length of 8' in the prototype vs 16' in the full scale unit. The conditions along the horizontal length of the unit are precisely the same in the prototype and full scale units.

10.0 CONCLUSIONS

1. A solar still for producing potable water from a weak brine solution is very viable by using black painted corrugated steel to absorb the sun's energy and transfer that energy to evaporate the brine solution, and condense the produced water vapor on a different water-cooled condensing surface.
2. A teepee style design is ideal from many standpoints and it is especially ideal from the standpoint of strength required to withstand high winds.
3. The capital cost of a unit to supply potable water to a community of 500 citizens will be about $100,000, resulting in a $10,000/yr capital charge for a 10 year write off.
4. At maximum, the operating cost for the full-scale unit will be about $80,000/yr.
5. At maximum, the water cost without any credit for salt sales will be about $67.25/kGal.
6. The water cost with $0.20/lb salt sales will reduce to $47.33/kGal.
7. An optimistic scenario assumes community volunteer labor and $0.33/lb salt sales, giving the community water at zero cost. The cost of salt sales offsets all of the operating cost excluding operating labor.
8. This unit is only economically viable for communities for which water is significantly more expensive the average to maximum cost in the US.

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12.0 AUDITS

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Date: March 18, 2014

H_2OGS*
Department of Chemical Engineering University of Arkansas

Subject: Review and comments on H_2OGS* solar brine concentrator

Dear H_2OGS*,

I have reviewed your report on a method of producing potable water from a brine well in Alamogordo, New Mexico. My comments are focused on my knowledge of water chemistry and water treatment associated with the project. I must start by saying that I think this is a very ingenious idea that builds on the strengths of the potential location of the system. My comments are made to optimize, fine-tune, and possibly avoid any problems. My comments include the following:

1. With this being in New Mexico, there is a high incident of sunlight for the unit, and the air

is dry enough for the evaporation of the brine effluent. These are pluses for the system.

2. One of the main issues with solar-powered materials is the delivery of a constant source of power; for example, daytime versus nighttime, shorter winter days, cloudy days, etc. A key current potential drawback would be the need of a battery for the system; otherwise, water would only be produced during the daytime. Another possibility would be to have storage tanks for the water, so during peak hours, water can be stored in tanks for using during low hours for a more uninterrupted delivery.
3. The insolation (Table 1) is quite different between a peak in May and a low in December. How will you account for this difference? Insolation is directly related to panel size; furthermore, there are often a lot of losses so efficiency can be small. Will the size of the panels appropriate for the insolation available?
4. The water quality in Table 2 is a potential problem – the high concentration of sulfate can lead to very high scaling on the units (the sulfate will precipitate with many of the cations to form a scale on the surface). How will this be addressed?
5. Brine being sprayed on the backside of the plates might lead to corrosion issues. With the sulfate concentration (Table 2) in water, there will be sulfuric acid in the water, so corrosion should be addressed with the selection of the stainless steel to be used. Furthermore, are there any issues with the different density of brine?
6. The plants proposed in the evaporation pond are discussed to thrive in salt; however, again, there is a concern that with the high sulfate concentration, and the potential for sulfuric acid in the water.

Overall, this solar brine concentrator has a potential to be of significance especially for small communities that can handle production fluctuations, and need potable water. My comments focus on some questions to further refine the process. If there are any further questions or comments regarding my evaluation I can be reached at 419-530-8267 or email: Isabel.Escobar@utoledo.edu.

Sincerely yours,

Isabel C. Escobar, PhD
Professor of Chemical & Environmental Engineering
Interim Assistant Dean for Research Development and Outreach, College of Engineering The University of Toledo
Toledo, OH 43606

H_2OGS,

This is a well written paper and the idea is a great one. I made a few comments in part 7.0 Health safety and environmental considerations. Take a look. Those were the only comments I had.

I hope you all do well and I will see you this summer!

Thanks,

Chad Henson
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Phone: (270) 746-6868
Fax: (270) 746-6815
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347 Central Avenue
Bowling Green, KY 42101

The above is an email H2OGS received on March 19, 2014 from Mr. Chad Henson (chenson2@valspar.com). He made corrections within our report using the track changes feature in Microsoft Word. All of her changes are shown below and have not been altered in anyway. The changes he made will be underlined, while the original text will be unchanged.

HEALTH SAFETY AND ENVIRONMENTAL CONSIDERATIONS

In addressing health, safety, and environmental regulations, H_2OGS investigated regulations on both the state and federal level. For the environmental regulations, possible water runoff and drinking water standards were considered.

The New Mexico Environmental Department requires National Pollutant Discharge Elimination System (NPDES) permits established by the Clean Water Act Section 402. The

Environmental Protection Agency (EPA) outlines the categories which are required to obtain NPDES permits. To remain in accordance with the New Mexico Environmental Department and the EPA a Storm Water Pollution Prevention Plan (SWPPP) will need to be created and the appropriate NPDES permits will need to be acquired[3,9,11]

The Safe Drinking water act regulates the quality of Americans' drinking water[13]. According to the EPAs National Primary Drinking Water Regulations the barium level in drinking water must be under two ppm. Nitrates must be under ten ppm. The potential health effects from long term exposure for amounts higher than the regulated amount for barium is increased blood pressure and nitrates can cause infants under six months of age to become seriously ill[12]. I would add the process taken to ensure barium and nitrate levels are within acceptable ranges. Typically by periodic monitoring / grabbing water samples.

H_2OGS strives to have a safe unit and procedure for the city of Alamogordo. Safety precautions need to be taken for thermal, weather, and unit operations. The unit will operate at around 45-70◦C so protective gloves should be worn and the drinking water that is outputted should be given adequate time to cool. If unplanned contamination occurs during the concentration procedure continue operating under a warning until the contaminated water leaves the still and then thoroughly clean out the apparatus. During the summer season the concentrator should be operated at times to avoid the heat, during the morning or evening. Workers should be fully hydrated throughout the entire day. Should contractor safety be added to this section? How will you train and what safety related activities will the contractor need training on? This should include forklift operations, site safety rules, evacuation procedures (gathering points), first aid, who to contact if an emergency occurs, etc.

H_2OGS,

See the comment below from one of our graduating seniors. Best wishes to you all in your final stages!!

Ms. Liz

Sent from my iPhone

Begin forwarded message:

From: Devon PridGeon <devon.pridgeon@gmail.com>

Date: March 20, 2014, 9:05:47 PM CDT

To: "Morrow, Liz" <MorrowL@lincolnu.edu>

Subject: Re: FW: WERC Paper Review

Hello,

My name is Devon PridGeon I am a senior at Lincoln University majoring in Chemistry. I am the founder and President of the Lincoln University Student Affiliates Of The American Chemistry Society Chem Club. I thought the paper was very good and well put together.

Thank you,

Devon PridGeon

The above is the email audit H2OGS received on March 20, 2014 from Devon PridGeon (devon.pridgeon@gmail.com). All comments were in the email and no comments were made within the report.